MICROCOMPUTER APPLICATION TO COMPUTE A SHIP'S DRAFT AND LONGITUDINAL STRESS

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MICROCOMPUTER APPLICATION TO
COMPUTE A SHIP'S DRAFT AND
LONGITUDINAL STRESS

by

Daniel Samuel Gomez

March 1977

Thesis Advisor: R. W. Hamming

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The paper introduces an algorithm capable of computing a ship's draft and stress on a small computer system or programmable calculator. The report has also demonstrated how the large amount of data in the ship's capacity tables can be effectively reduced for incorporation into the program. The algorithm was implemented in the BASIC language and was intended to require the minimum of user interaction while providing the maximum useful output.

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Microcomputer Application to Compute a Ship's Draft and Longitudinal Stress

by

Daniel Samuel Gomez
Lieutenant, United States Navy
B.S., New Mexico State University, 1969

Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The paper introduces an algorithm capable of computing a ship's draft and stress on a small computer system or programmable calculator. The report has also demonstrated how the large amount of data in the ship's capacity tables can be effectively reduced for incorporation into the program. The algorithm was implemented in the BASIC language and was intended to require the minimum of user interaction while providing the maximum useful output.

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I. INTRODUCTION

This paper develops a computer application to enhance the speed, accuracy and ease with which the calculation of a ship's draft and longitudinal stress can be made. The calculations are based on the user's input of the desired loading of the ship.

This application was designed to allow the user to first make any changes desired concerning the ship's load distribution, and then automatically calculate and display the ship's new draft and stress condition based on these changes. The program then queries the user if he desires a hard copy of the present load distribution and the associated draft and stress conditions. The program then loops back to the beginning and asks if the user wishes to perform further calculations or desires to terminate. The program redisplays input values to the user to verify that the correct input was entered.

The principle reason for using a computer in this area is that it tends to reduce errors made in the recording, computing and transferring of data in the numerous calculations. The amount of input information required from the user is minimized in order to reduce human error.

The first step in this research was to find out how to reduce the standard extensive table of numbers to a volume small enough to be stored in a small computer system. The word "computer" as used in this paper has been used to refer to a small microcomputer system as well as the desk top programmable calculators capable of having extended memories. It was also necessary to provide the output in a form acceptable for record keeping to eliminate errors in transferring data.

II. NEED FOR A COMPUTER APPLICATION

The calculation of a ship's draft and stress condition involves the extraction of information from various tables. This information along with the ship's present load distribution determines the ship's loading condition.

In principle the mathematics involved are relatively simple, but due to the number of calculations required, along with the many table lookups and transfers of data, a high probability exists that errors may occur. Depending upon the number of changes occurring to the load distribution between calculations, the entire process could involve 140 table entries and transfer of data, 280 additions and subtractions, and 280 multiplications and divisions.

In order to insure optimum loading of the ship in situations where a proposed load change of the ship is being anticipated, several different loading plans have to be evaluated to find the best resultant draft and stress conditions. Owing to the repetitive nature of the calculations, it is very easy to skip a line of computation or even include the same line of computation more than once in the final result. Furthermore, manual calculation time, even for an experienced individual, can take over an hour

for each loading plan configuration (allowing for the checking of all calculations) and thus restricts the number of proposed load changes that can be considered. Unfortunately, even after the calculations have been checked, it still happens that an error passes undetected and can cause a sizeable error in the final results.

A computer program which calls for the minimum amount of input from the user can greatly reduce the chance of human error as well as quickly provide a mathematically correct answer. Another advantage is that the output can be printed in a form suitable for record keeping.

III. BACKGROUND

The ship's data used in this paper was taken from the AOR-1 class fleet replenishment oiler, with the tank capacity tables coming from the U.S.S. Wichita (AOR-1). This was done for several specific reasons. The ship was undergoing a restricted availability in San Francisco which meant it would be stationary for an extended period of time, and as the author's last duty station, access to the required information was easy. The AOR-1 class ship represents a specific case where an application, such as the one proposed in this paper, is definitely needed. Being a cargo type ship, the load condition of the ship can often change by large amounts from day to day and even hour to hour. Prior to any changes being made, the resultant draft and stress must be computed and submitted to the commanding officer for his approval. After the change is made, the actual resulting draft and stress condition must again be calculated for record purposes.

During the ship's construction in the late sixties, a device called a "LODICATOR" was designed for the ship's class as a draft and stress computer at a cost of $100,000.00 per device. The device allowed the user to enter the current

load distribution by entering the appropriate tonnage of each space on the dial for each space. After all the load information was entered, several switches and dials had to be operated to obtain the desired results. All output appeared on meters, and the results had to be copied by the user. In January, 1973, it was determined by the Naval Ship Systems Command that the "LODICATOR" only produces accurate results for stillwater conditions and has no validity for actual underway sea conditions. Therefore, its use was discontinued leaving only strictly manual methods. To date, no solution has been found that would correct the problems and make the "LODICATOR" useful.

Since the basic principles for determining the draft and stress were the same no matter what type ship is under consideration, using the methods presented here, the same, or equivalent computations can be done on small, inexpensive computers.

In simple terms, the draft of a ship is merely an indication of the number of feet and inches that the ship extends below the surface of the water. The draft is determined for both the forward and after ends of the vessel. The trim is the difference in the drafts of the two ends of the ship. The trim is said to be "by the stern" if the after draft is greater than the forward draft and if the

opposite is true, the trim is said to be "by the head." If the drafts, both forward and aft are the same, the ship is said to be "on an even keel." It is of utmost importance to know accurately the ship's draft in order to know the amount of water under the vessel as well as how to expect the ship to handle in various weather conditions.

It is obvious that it is also necessary to know the stress on a ship in order to prevent structural damage and possible loss of the ship in rough weather. Structural failure of the ship's girder may be due to one or a combination of cracking, fatigue failure and instability.

Within a ship, structural stresses are usually considered in two groups. First, hull girder stresses result from the differences between the upward buoyancy forces of the sea and the downward forces resulting from the distribution of the various weights within the ship including the ship structure itself. Second, local stresses are caused by hydrostatic pressure, concentrated loads of equipment and dynamic loading. It is hard to conceive of a situation where the forces due to gravity and water pressure exactly cancel out along the entire ship's length. Even in still-water, this is exceedingly unlikely. There is, therefore, an uneven loading along the ship and, because the ship is an elastic structure, it bends. In a seaway, a vessel is

similar to a beam with supports and distributed loads. The supports are the forces from the waves and the load is the weight of the ship and its cargo.

The worst condition of loading and support for a ship occurs when the ship heads into or away from the sea with waves approximately equal in period to the length of the ship. When a ship's bow and stern are each riding a crest, and the midships is in a trough, then the ship will bend with compression and the main deck and tension in the keel. The ship is then said to be "sagging" and the main deck tends to buckle due to compressive stress, while the keel stretches due to tensile stress. When the wave is advanced by half its length so that the crest is amidships, and the bow and stern are in troughs, then the stresses are reversed. The main deck is in tension and the keel area is in compression. In this condition, the ship is said to be "hogging." The stresses occurring when experiencing hogging and sagging conditions are also known as "longitudinal stress."

It is important to understand that longitudinal stresses also exist in still water conditions due solely to the loading of the ship. However, a far greater concern arises when the action of the waves adds to the stillwater stresses. It is supposed that a ship never meets a sea which imposes

more severe bending on the ship than that caused by a single wave such that the distance from crest to crest is equal to the length of the vessel. The ship is assumed to be momentarily stationary, balanced on the wave with zero velocity and acceleration, and the response of the sea is taken to be that appropriate to static water. There is no universally accepted standard ocean wave which may be assumed for the standard longitudinal strength calculation. While the shape of the troughs is agreed to be trochoidal, the ratio of length to height varies. A trochoid is a curve produced by a point at radius "r" within a circle of radius "R" rolling on a flat surface (see Figure 1).

The starting point for determining a ship's draft and stress condition is to find the location and magnitude of all weights which are not actually part of the ship's structure. This includes cargo, water, fuel and ammunition.

Determining the draft of the ship while not underway requires only visual observation of the draft marks from the pier or a ship's boat. This process becomes more difficult when the ship is underway for extended periods of time. The most important step in accurately determining the draft is determining the exact disposition of all weights on board and obtaining an accurate visual draft just prior to the ship getting underway. This information is recorded

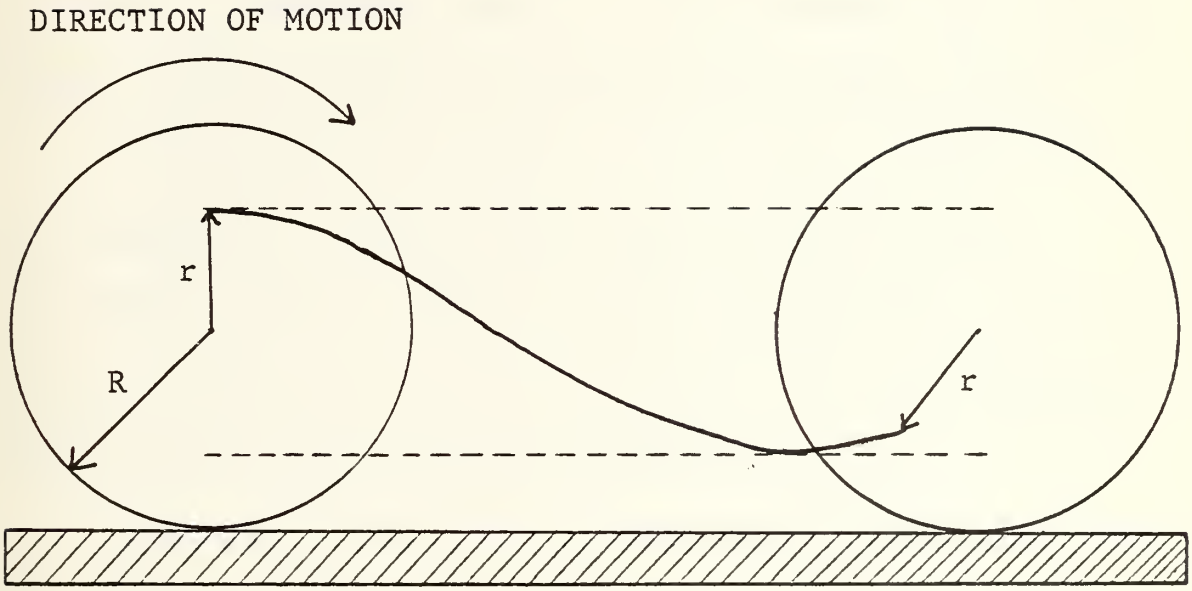

Figure 1. Trochoidal Curve

and is used as "day 1" data. Each day underway, the draft is determined relative to the day 1 data. While underway, all changes to the distribution of weights are recorded, such as the amount of cargo transferred to other ships, water consumed and produced on board, and the amount of fuel consumed. The amount of change in long tons is determined for each location which has changed since day 1. Next, the ship's "Deadweight Scale" or "Trim Tables" are entered. These two names refer to the same table, which is constructed by the ship's builder. This table contains the information to calculate the change in draft based on changing a specific number of tons in a specific location. Figure 2 represents a portion of the trim table/deadweight scale for the U.S.S. Wichita (AOR-1).

The stress of the ship is based upon the present load distribution. Tables are provided in the ship's damage control book for the calculation of longitudinal stress in the stillwater, hogging and sagging conditions. The three tables are essentially the same except for column D which represents the change in stress per 100 tons. Figure 3 is a portion of one of the tables to help in the discussion of the calculations. The present load in long tons was entered into column B for each location. Column A was subtracted from column B and the result divided by 100 and entered into

PORT AND FORWARD LEVERS
ARE MINUS

TANK NO.	LOAD TONS	CHANGE DRAFT FP INCHES	CHANGE DRAFT FORWARD MARKS INCHES	CHANGE DRAFT AP INCHES	CHANGE DRAFT AFTER MARK INCHES
6-A-OW	238.03	14.423	13.544	- 9.017	- 7.918
6-21-OW	570.85	31.400	29.524	-18.647	-16.301
6-25.5-0-GG	604.35	30.688	28.886	-17.354	-15.102
6-29-0-JJ	437.31	20.369	19.199	-10.842	- 9.379
6-31-0-JJ	1632.32	69.861	65.940	-34.705	-29.804
6-34-0-JJ	2025.96	74.122	70.168	-31.317	-26.375
6-34-1-JJ	888.18	32.120	30.413	-13.379	-11.246
6-34-2-JJ	887.41	32.092	30.387	-13.367	-11.236
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

Figure 2. Deadweight Scale/Trim Table (AOR-1)

HOGGING
TABLE FOR ESTIMATING LONGITUDINAL STRESS

Description of Load	Frame No.	LOAD IN TONS		B-A / 100	Change Stress In Tons/Sq In.	
		Full Load (A)	Cond (B)	(C)	Per 100 Tons (D)	Cond (C)x(D) (E)
Fwd Peak	0-17	-			+.114	
Salt Water Ballast	21-25	-			+.094	
Aviation Gas	25-29	658			+.077	
Fuel Oil or JP-5	29-31	-			+.060	
JP-5	31-34	1224			+.047	
JP-5	34-39	3660			+.022	
Dry Cargo	39-44	84			-.009	
Fuel Oil	39-44	1674			-.010	
Fuel Oil & JP-5	44-49	4845			-.042	
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Dry Cargo	31-37	133			+.032	
Dry Cargo	44-53	283			-.054	
Refrigerator Cargo	60-65	150			-.010	
Total Loads		24597		Total Change		
LightShip, Stores, etc.		13460	13460	Correction		
Total Displacement		38057		F/L Stress		5.13
				Resultant Stress		

Figure 3. Table for Estimating Longitudinal Stress

column C for each location. Column C was multiplied by column D and the result entered into column E. All the values in column E were added together and the sum is the total change in stress. Column B was totaled to produce the ship's displacement. The ship's displacement was used to enter the tables for change in displacement to determine the correction factor to be applied (see Figure 4). The total change in stress, the correction factor and the full load stress were added to give the resultant stress which must be less than or equal to a maximum limiting value. This limiting value depends on the class of ship, and for the AOR-1 class is 8 tons per square inch.

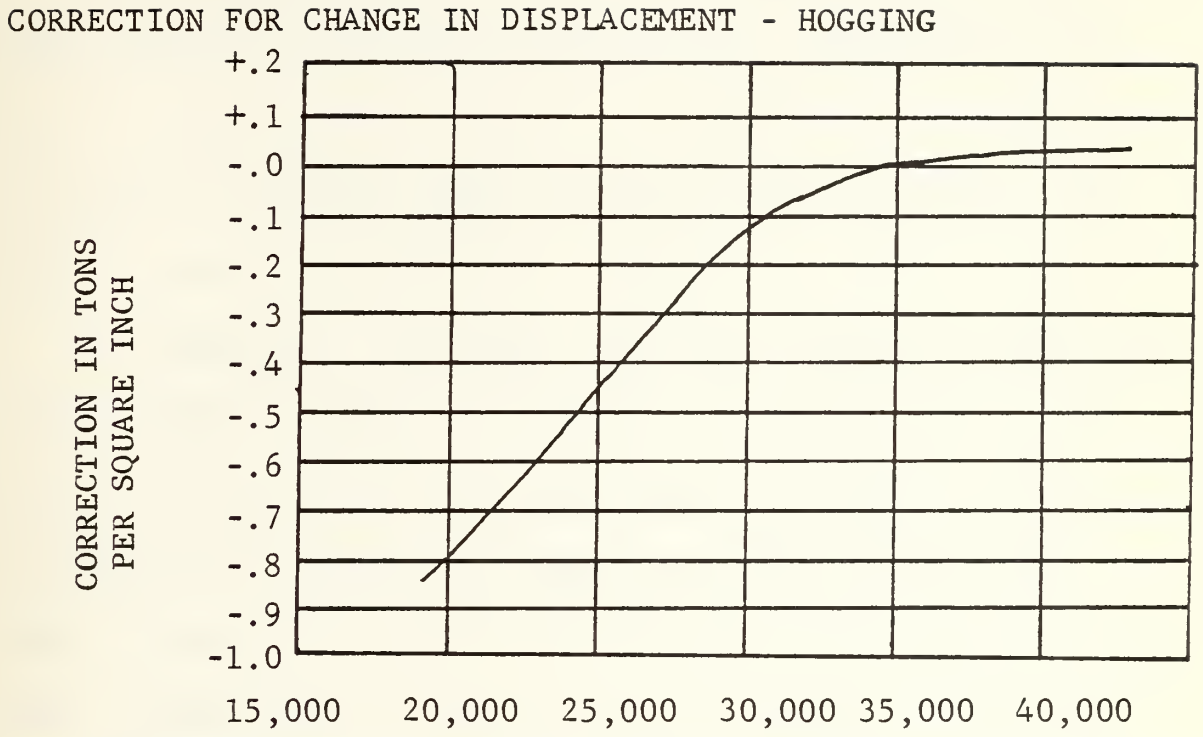

Figure 4. Correction for Change in Displacement

IV. NATURE OF THE PROBLEM

A. ANTICIPATED PROBLEM AREAS

Past experience has shown that no matter how careful one attempts to be while entering data, undetected errors still manage to occur. One way to help this situation was to require as little input as possible and to "echo" the values back to the user for a check.

All tanks on a ship have associated capacity tables for determining the amount contained in the tank. If a tank has been fitted with a sounding tube, in which a tape can be lowered to measure the depth of liquid ("sounding"), then a previously prepared table gives the capacity of the tank corresponding to every inch of sounding. This table was complicated by the fact that the sounding tube is usually sloping, and may have bends in it, so that the sounding tape does not show the vertical depth of liquid. In order to construct this sounding table, a capacity curve, to be explained later, must first be drawn. The sounding tube itself was then measured and drawn on the same paper and to the same scale as the capacity curve. The scale of feet and inches was laid off on the sounding tube, and the corresponding capacities read from the capacity curve. An

"ullage" is the distance from the tank top down to the surface of the liquid in a tank. Since these measurements deal with vertical distances, different tables must be prepared. These tables are called ullage tables, and they tabulate the capacity corresponding to a given ullage.

The type of tables used on a particular ship depends on its construction and ships may in fact have both. In either case, the capacity is recorded and the number of long tons in the tank determined. This is merely the product of the number of gallons times the density of the liquid in the tank divided by 2240.

Each tank on each ship has its own unique capacity table and each table contains anywhere from 100 up to 700 or more entries depending upon the depth of the tank. From past personal experience, it is very easy to take the wrong data from a table if great care is not used. Location of the desired sounding/ullage is not difficult, but the transferring of a five or six digit number can often result in a transposed digit or wrong repeated digits.

Tank capacity curves are simply curves showing the capacity corresponding to any depth of liquid. This curve is made by calculating the volume of the tank up to a sufficient number of levels, plotting these volumes against a vertical scale of depth, and drawing a curve through the

calculated points. This curve will not necessarily be smooth, for its slope depends on the area of the horizontal planes through the tank. Figure 5 illustrates how the shape of a capacity curve is affected by the shape of the tank. All of the conditions shown will seldom be found in any one tank.

One problem was how to develop an interpolating polynomial that would accurately reproduce the tank capacity curves and thus allow the sounding/ullage table data to be regenerated rather than stored.

It should be realized that some error occurs in the taking of the depth of liquid in the tank but that this can be minimized by allowing only trained individuals to perform this important task, with a second person checking the results of the first and comparing the results against the capacity indicated by the tank level indicator.

To allow the input of the tank sounding/ullage so that the user could be relieved of the responsibility of entering tables and correctly transferring data, the obvious problem was how to reduce the size of the tables of tank capacities to a small enough amount to be acceptable to a small computer system. In order to store all the tank capacity data just from the original tables for an AOR class ship would require 70 K bytes of storage area,

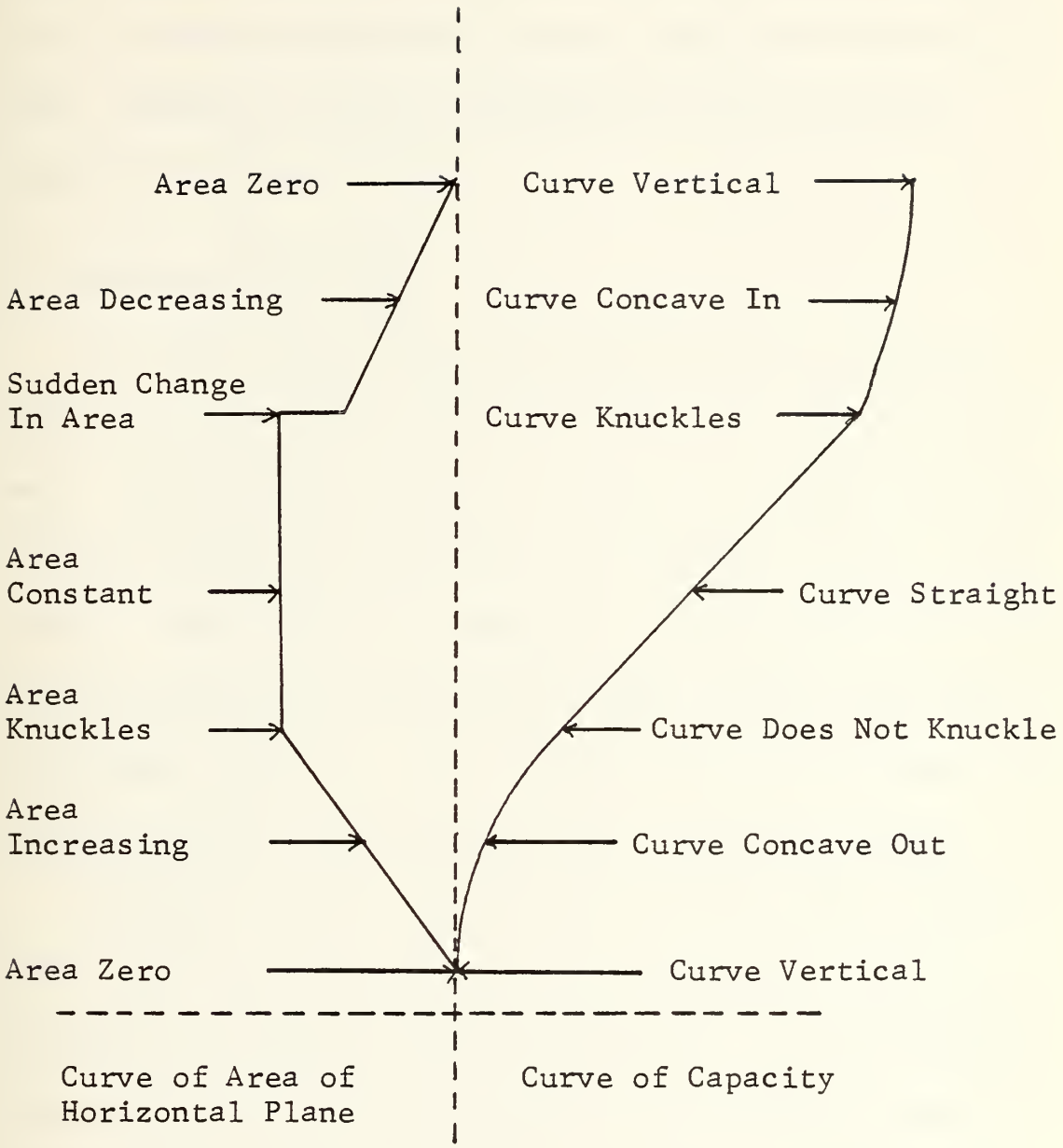

Figure 5. Tank Shape vs. Capacity Curve Shape

assuming four bytes per word. The original purpose of this paper was to provide an algorithm that would require as little memory as possible so that a small system could be used, hopefully without the added cost of expensive secondary storage devices.

B. PROPOSED SOLUTIONS

To reduce errors it was decided from the beginning that user interaction would be kept to the absolute minimum. Information supplied by the user includes the identification number of the space to be changed and the change itself. Tanks would be changed by entering the new sounding/ullage in feet and inches while cargo spaces would have the new tonnage entered. Also required would be the day 1 draft, forward and aft, each time the day 1 data is changed.

In order to solve the reduction of the tank sounding data, first the shipbuilders were contacted to gain some insight as to how the tables were made. At first glance, the tank capacity curves appeared to be a smooth curve - possibly a quadratic or cubic equation, but this was not the case. The naval architect contacted, explained that the tank sounding tables were generated by a computer program utilizing information from three separate curves: tank capacity versus ship's trim; tank vertical center of

gravity; and height of sounding tube above the baseline. The information was obtained at numerous points especially where any definite changes in the internal tank structure occurs, and therefore a specific tank could contain any number of data points. The resulting information was processed by computer and a parabola passed through sets of points. The table values were generated using an interpolating polynomial. This means that each tank capacity curve is actually a series of many small parabolic curve sections. The first course of action was to discover, and to break each tank down into, its sets of parabolic curves, and then to generate interpolating polynomials that would accurately reproduce the table values. To help in this endeavor, difference tables were used (see Figure 6). The intervals between "x" values are usually equal to simplify calculations. It is easily proved that the "n"th order differences of any "n"th degree polynomial are constant. Using this fact, table entries from the tank capacity tables were used as data in a difference table, and the second differences were observed to be relatively constant sequences of terms, thus defining the separate individual quadratics in each tank (see Figure 7). The table values at every six inches were used to generate the difference tables.

X	f(X)	Δf	$\Delta^2 f$	$\Delta^3 f$
X_o	f_o			
		Δf_o		
X_1	f_1		$\Delta^2 f_o$	
		Δf_1		$\Delta^3 f_o$
X_2	f_2		$\Delta^2 f_1$	
		Δf_2		$\Delta^3 f_1$
X_3	f_3		$\Delta^2 f_2$	
		Δf_3		
X_4	f_4			

$$\Delta f_o = f_1 - f_o$$

$$\Delta f_1 = f_2 - f_1$$

$$\Delta f_2 = f_3 - f_2$$

$$\Delta f_3 = f_4 - f_3$$

$$\Delta^2 f_o = \Delta f_1 - \Delta f_o = (f_2 - f_1) - (f_1 - f_o) = f_2 - 2f_1 + f_o$$

$$\Delta^3 f_o = \Delta^2 f_1 - \Delta^2 f_o = f_3 - 3f_2 + 3f_1 - f_o$$

Figure 6. General Difference Table

(Feet) X	(Gallons) f(x)	Δf	$\Delta^2 f$	
0.5	2185			
		3959		
1.0	6144		39	
		3998		
1.5	10142		39	
		4037		
2.0	14179		39	
		4076		
2.5	18255		38	
		4114		RELATIVELY CONSTANT — ONE SUBCURVE
3.0	22369		40	
		4154		
3.5	26523		38	
		4192		
4.0	30715		38	
		4240		
4.5	34955		640	← JOINING POINT
		4880		
5.0	39835		54	
		4934		
5.5	44769		54	
		4988		
6.0	49769		54	
		5042		RELATIVELY CONSTANT — ONE SUBCURVE
6.5	54799		55	
		5097		
7.0	59896		54	
		5151		
7.5	65047		54	
		5205		
8.0	70252		55	
		5260		
8.5	75512			

Figure 7. Sample Tank Difference Table

After the approximate location of the end points of each subcurve was determined, table values for each inch were used in a second difference table to determine the exact point where the subcurves were joined. A computer program was developed to help in the processing of the difference tables and provided output in the form of Figure 7. After each curve's end points were determined, the next task was to generate an interpolating polynomial for each subcurve in order to regenerate any desired value in the tables. Newton's interpolation formula with divided differences was selected because it does not require the interval to be the same between points. To obtain the maximum possible reduction of data, the three coefficients obtained from Newton's method along with their respective points were reduced to the basic polynomial form, $ax^2 + bx + c$, so that only the three terms a, b and c need be stored in order to regenerate any point within the interval covered by the subcurve. Using this method of reduction, the original 70 K bytes of capacity table data was reduced to 4.5 bytes. A separate program was written to test each interpolating polynomial for every point in the interval.

In reviewing all the table entries, two obvious table entry errors were located and five additional entries were suspected of error in the original capacity tables. The

two obvious errors were clearly made in transferring the numbers into the original table supplied by shipbuilders. The suspected errors were felt to be due to the same reason, but the variations from the true values were not large enough to make the errors obvious. Thus another useful purpose of breaking down the capacity curves is to check the original table data for errors. Excluding the suspected points, the interpolating polynomials generated values that were within one gallon of the table value and the worst computed point only produced an error of .1% from the table value.

V. PROGRAM IMPLEMENTATION

The program was written in the version of BASIC used at the W.R. Church Computer Center, Naval Postgraduate School. This version is an adaptation of the University of Washington Basic Interpretive Compiler (UWBIC). The program was divided into two separate programs, one computing the draft and the other the stress, because the compiler was not of sufficient size to run the entire program as it appears in appendix A. Another problem area arose from the limited size of the data stack, so for the draft program only six tanks were tested at a time.

The complete program requires 1627 constants be read into four arrays in order to perform the subsequent calculations and compute the draft and stress. In the test programs, the data were read in through the use of DATA statements. In an actual operating system, it would seem more logical to keep this data in a read only memory or to access the data from a file stored on a secondary storage device depending on the particular system used.

In more detail, array X contains all the interpolating polynomial data for converting tank soundings into gallons. The array is really made up of a series of four elements.

The first element contains the upper endpoint of the particular subcurve and the next three elements contain the interpolating coefficients a, b and c. The data were stored in the same order as the tanks appear in the tank capacity tables. For each specific tank the polynomials were stored in ascending order of tank height.

Array Y contains the data necessary for the calculation of the draft and stress as well as space to save values for later output. Each row represents one of the forty-six spaces on the ship and the columns represent the specific constants pertaining to each space. The first six columns contain data generated by the program and were stored for later reference. Column one contains the day 1 tonnage, column two the present tonnage, column three present gallons, columns four and five the present sounding in feet and inches respectively, and column six the present contents in barrels. Columns three through six remain blank if the space is not a tank. Columns seven through sixteen contain the constants necessary for the changing of spaces' contents and the draft and stress calculations. Column seven contains the space I.D. reference number, column eight the maximum sounding allowable in each tank, column nine the specific gravity of the contents of the tank, columns ten and eleven the change in draft per hundred tons change

forward and aft respectively, column twelve the data from column A of Figure 3, columns thirteen through fifteen the data from column D of Figure 3 for hogging, sagging and stillwater respectively, and column sixteen the starting point in array X for each tank. Arrays W and U contain the interpolating data for generating the hogging, sagging and stillwater displacement corrections in the stress calculations (see Figure 4).

In order to reduce human error, the program checks the input to as great an extent as possible. When an incorrect input value is detected, if the error was simple such as not receiving a 1 or 2 for a yes or no question, a statement to that effect will be displayed and the question will be asked again. In other cases the user will be queried as to whether or not he desires to see the instructions again before the question is asked again.

In appendix A subroutine 200 was used in the test program to fill the array data from DATA cards. It was left blank here because how the data was accessed would depend on the system. Another portion of the program not appearing occurs at the end of subroutine 800. A method must be incorporated to save the data in columns one through six of array Y so the user is not required to manually enter this data each time the program is loaded.

Appendix B is a sample program run and Appendix C is a sample of how the required initializing data is stored.

VI. PROGRAM TESTING

Since the program was too large for the BASIC compiler on the IBM 360, the 24K microcomputer development system in the microcomputer laboratory at the Naval Postgraduate School was used to obtain information concerning the program size and feasibility of using a system of this size. The system operates using BASIC-E which required some minor changes to the program. The program was compiled and the following statistics obtained: 7672 bytes of array area, 4356 bytes of run-time code, and 572 bytes of memory for variable and constant storage for a total of 12.6 K bytes. One must remember this figure does not include the 6.6 K bytes of initializing data. The 12.6 K bytes of program was too large to be executed on the 24 K system as Figure 8 shows only about 8.5K available for user programs. If the initializing data were stored on a secondary storage device, the program could be executed on a 32K system. If the data were stored in read only memory in the computer's main memory space, some 35K bytes would be required.

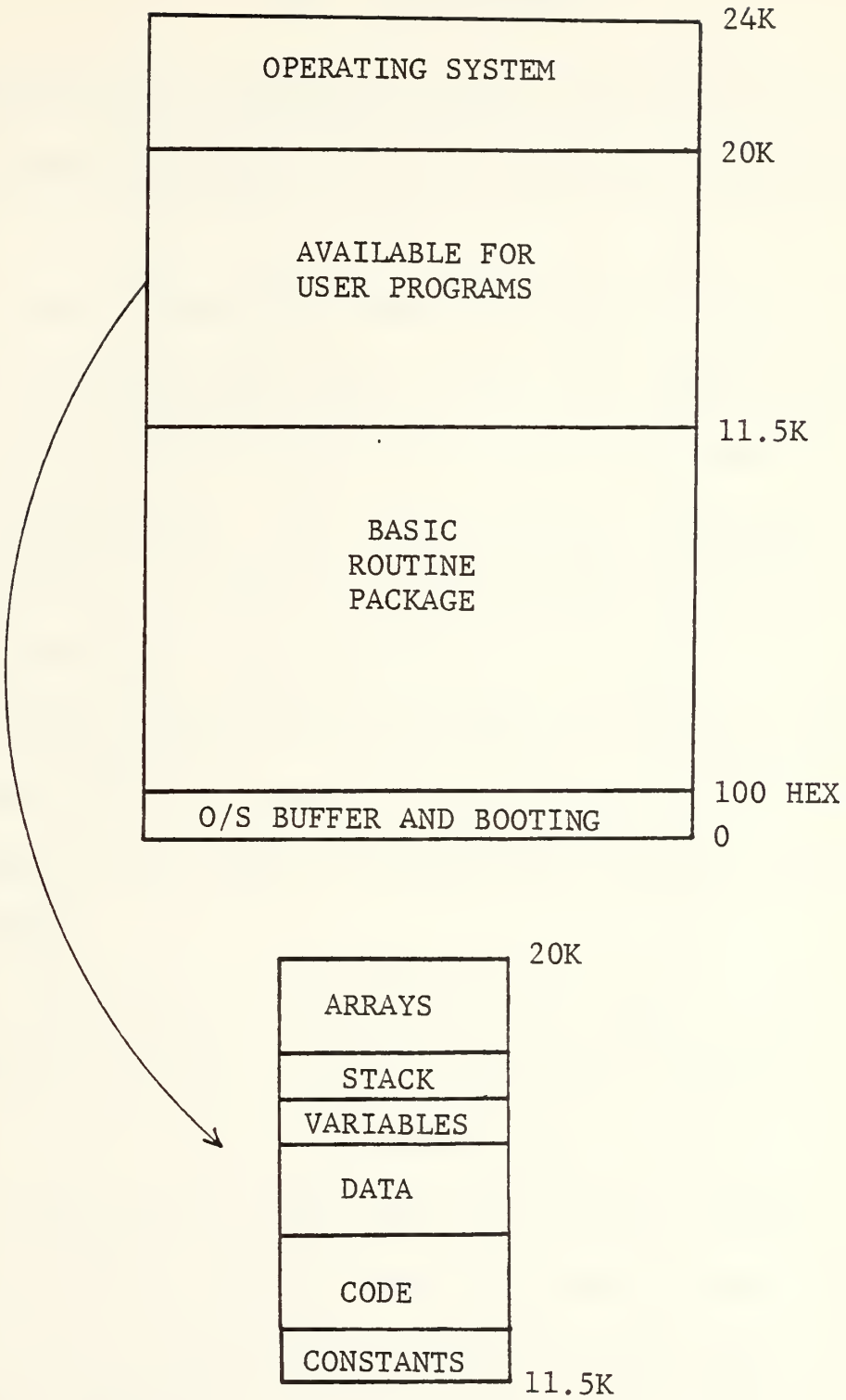

Figure 8. Memory Allocation Map

VII. CONCLUSIONS

Currently, the proposed computer application is capable of accurately computing the draft and stress conditions of a ship.

One way to reduce the amount of initializing data would be to require the user to enter the capacity tables and enter the number of gallons in the tank rather than the sounding/ullage. This would obviously eliminate the need for the 4.5 K bytes of interpolating polynomial data, but put much more responsibility on the user to correctly convert the sounding/ullage and then to correctly transfer the number into the system. Although a solution, it was the intent of this paper to require the minimum of user involvement.

For the effective use of this application it would be necessary to be able to save the volatile information contained in array Y prior to terminating the program. This would be necessary so that only the specific changes from use to use need be entered into the system as they occur.

The interpolating data generated in this paper could be easily produced by the shipbuilder at the same time the data is processed to produce the tank capacity tables.

As to what types of systems would be feasible for this application, three systems appear most likely.

First, there are desk-top programmable calculators already being manufactured that would be adequate. Commander Naval Surface Force, U.S. Pacific Fleet, has recently completed a study where several 32K byte programmable calculators and associated peripherals were tested aboard Navy ships for a period of six months. The systems were tasked with performing storekeeper functions, celestial navigation, maneuvering board solutions, etc. The results were excellent from both performance and maintenance viewpoints. Second, a dedicated system could be designed from available microprocessor components. The memory could be mostly read only memory with some random access memory for the volatile data and some kind of terminal for the input and output of information. This system would require no secondary memory. Third, a general purpose microcomputer system could be used to run this application on. The system could be large enough to handle all the various applications aboard ship.

On large cargo ships such as the AOR-1 class ship, a programmable calculator or a small dedicated system would more than replace the "LODICATOR" and existing manual methods.

Another useful application along the lines of this paper would be to use the data to compute other damage control information such as righting arms and reserve buoyancy for use in the event of fire and flooding aboard ships. Once adequate computing power is available on board ship, many other applications, both old and new, can probably be found.

```
   REM  DRAFT AND STRESS COMPUTER


   REM  **********************
   REM  MAIN PROGRAM
   REM  **********************

    DIM  Y(46,16),X(1140),W(3,7),U(3,7)
    LET F1=0
    GOSUB 200
    GO TO  150
102 PRINT 'TO CONTINUE,INPUT 1. TO TERMINATE,INPUT 2.'
    READ A
    IF A=1 THEN 150
    IF A=2 THEN 130
    PRINT 'INPUT VALUE MUST BE A 1 OR 2.'
    GO TO 102
130 PRINT 'DO YOU REALLY WANT TO STOP'
    GOSUB 250
    IF A=1 THEN 180
    IF A=2 THEN 150
    PRINT 'INPUT VALUE MUST BE A 1 OR 2.'
    GO TO 130
150 GOSUB 540
    GOSUB 800
    GO TO 102
180 STOP



   REM  **********************
   REM  SUBROUTINE 200
   REM  FILL ARRAY DATA HERE.  METHOD DEPENDING ON SYSTEM
   REM  IN USE.  DATA COULD BE READ FROM ROM, A FILE ON
   REM  TAPE/DISC OR BY USE OF DATA STATEMENTS.
   REM  **********************

200 PRINT
    RETURN
```

```
    REM  **********************
    REM  SUBROUTINE 210
    REM  INSTRUCTIONS
    REM  INSTRUCTIONS ARE DISPLAYED UPON REQUEST BY THE USER.
    REM  THE USER IS ASKED PRIOR TO THE FIRST EXECUTION OF
    REM . THE PROGRAM AND AFTER INPUT ERRORS.
    REM  **********************



210 PRINT 'DO YOU WANT THE INSTRUCTIONS'
    GOSUB 250
    IF A=1 THEN 220
    IF A=2 THEN 230
    PRINT 'INPUT MUST BE A 1 OR 2.'
    GO TO 210
    PRINT
    PRINT
220 PRINT 'ALL INPUT IS NUMERICAL WITH COMMAS SEPERATING'
    PRINT 'ENTRIES WHEN MORE THAN ONE INPUT ASKED FOR.'
    PRINT
    PRINT 'WHEN DESIRING TO CHANGE THE AMOUNT IN A CERTAIN '
    PRINT 'SPACE,THE SPACE IS DESIGNATED BY FORMING AN I.D.'
    PRINT 'NUMBER FROM THE SPACE NUMBER.  '
    PRINT
    PRINT 'FOR SHIPS TANKS ,THE I.D. IS FORMED'
    PRINT 'BY COMBINING THE SPACE FRAME NUMBER AND THE SIDE OF '
    PRINT 'THE SHIP THE SPACE IS LOCATED TO FORM A NUMBER.  IF A LETTER'
    PRINT 'APPEARS ,OMIT AND INSERT A ZERO FOR EACH.'
    PRINT
    PRINT 'SPACES OTHER THAN TANKS ARE DESIGNATED BY USING THE'
    PRINT 'FRAME NUMBER FOLLOWED BY TWO ZEROS.'
    PRINT
    PRINT
    PRINT 'TO CONTINUE , INPUT 1.'
    READ A
    PRINT
    PRINT
    PRINT 'EACH SPACE IS DESIGNATED IN THE FORM:'
    PRINT 'LOWEST DECK-FORWARD FRAME -SIDE-CONTENTS'
    PRINT 'OR'
    PRINT '     6      -     44        - 0  -   JJ    '
    PRINT
```

```
      PRINT
      PRINT 'SOME EXAMPLES:'

      PRINT 'TANK 6-A-0-W      BECOMES 00.'
      PRINT 'TANK 6-25.5-0-GG BECOMES 2550.'
      PRINT 'TANK 6-44-2-FF    BECOMES 442.'
      PRINT 'SPACE 3-39-0-MM   BECOMES 3900'
      PRINT
      PRINT
      PRINT 'WHEN ENTERING DRAFT OR SOUNDINGS, ENTER FEET FIRST THEN'
      PRINT 'INCHES.IF EITHER FEET OR INCHES ARE ZERO, ENTER ZERO.'
      PRINT
      PRINT 'ENTER DATE AND TIME AS FOLLOWS,'
      PRINT 'DATE-    MO,DAY,YR  OR 02,17,72.'
      PRINT 'TIME-    1200'
230   RETURN
```



```
REM   **********************
REM   SUBROUTINE 250
REM   PROCEDURE TO PROCESS ANSWERS TO QUESTIONS WHICH ARE YES-NO.
REM   **********************


250 PRINT
    PRINT 'IF YES,INPUT 1. IF NO, INPUT 2.'
    READ A
    RETURN
```

```
    REM    **********************
    REM    SUBROUTINE 540
    REM    DETERMINE IF DAY 1 DATA IS TO BE CHANGED AND IF SO
    REM    REQUEST DAY 1 DRAFT FIGURES.  IF DAY 1 IS NOT TO
    REM    BE CHANGED , FLAG F3 IS SET TO SO INDICATE.
    REM    FLAG F1- INDICATES IF FIRST TIME THROUGH PROGRAM
    REM    C2      - INDICATES WHETHER DAY 1 OR PRESENT LOAD
    REM    D1      - DAY 1 DRAFT FORWARD IN INCHES
    REM    D2      - DAY 1 DRAFT AFT IN INCHES
    REM    **********************

540 LET F3=0
    IF F1=1 THEN 543
    GOSUB 210
543 PRINT 'DO YOU WANT TO CHANGE DAY 1 DATA'
    GOSUB 250
    IF A=1 THEN 544
    IF A=2 THEN 550
    PRINT'INPUT MUST BE A 1 OR 2.'
    GO TO 543

544 LET C2=1
    PRINT
    PRINT 'INPUT DAY 1 FORWARD DRAFT. FEET,INCHES'
    READ D1,D2
    PRINT
    PRINT 'INPUT DAY 1 AFT DRAFT. FEET,INCHES'
    READ D3,D4
    LET D1=D1*12+D2
    LET D2=D3*12+D4
    PRINT
    PRINT 'ENTER DAY 1 LOAD DATA AS FOLLOWS:'
    GOSUB 552
    GO TO 551
550 LET F3=1
    GOSUB 552
551 RETURN
```

```
    REM  **********************
    REM  SUBROUTINE 552
    REM  CHANGE TANK CONTENTS
    REM  ROUTINE CHANGES BOTH DAY 1 AND PRESENT LOADS
    REM  IF USER DESIRES AND THEN COMPUTES DRAFT.
    REM  C1   - POINTER TO ROW OF ARRAY Y REFERENCED
    REM  S7   - TANK SOUNDING IN INCHES FROM F/I
    REM  L1   - SPACE I.D. NUMBER
    REM  K4/K3- PRESENT DRAFT FORWARD,FEET/INCHES
    REM  K6/K5- PRESENT DRAFT AFT,FEET/INCHES
    REM  **********************


552 IF F3=1 THEN 561
553 PRINT
    PRINT 'ENTER NO. OF TANK OR SPACE TO BE CHANGED'
    LET C1=1
    PRINT 'IF YOU DO NOT WANT TO CHANGE ANY MORE'
    PRINT 'DATA, ENTER A NEGATIVE NO.'
    READ L1
    IF L1 LT 0 THEN 560
554 IF L1 = Y(C1,7) THEN 557
    LET C1=C1+1
    IF C1 GT 41 THEN 555
    GO TO 554
555 IF L1 = Y(C1,7) THEN 559
    LET C1=C1+1
    IF C1 GT 46 THEN 556
    GO TO 555
556 PRINT 'SPACE I.D. NUMBER INCORRECT'
    GOSUB 210
    GO TO 553
557 PRINT
    PRINT
    PRINT 'INPUT TANK SOUNDING. FEET,INCHES'
    READ F,I
    LET S7=F+(I/12)
    IF S7 LT 0 THEN 558
    IF S7 GT Y(C1,8) THEN 558
    GOSUB 650
    GO TO 553
558 PRINT 'TANK SOUNDING NOT WITHIN LIMITS'
    GOSUB 210
    GO TO 557
    PRINT
    PRINT
```

```
559 PRINT 'ENTER CONTENTS IN LONG TONS'
    READ T
    LET Y(C1,C2)= T
    PRINT 'VALUES ENTERED','SPACE I.D.','TONS'
    PRINT '    ',L1,T
    GO TO 553
560 IF C2= 2 THEN 565
561 PRINT
    PRINT
    PRINT 'DO YOU WANT TO CHANGE PRESENT LOAD DATA'
    GOSUB 250
    IF A=1 THEN 562
    IF A=2 THEN 565
    PRINT 'INPUT MUST BE A 1 OR 2.'
    GO TO 561
562 LET C2=2
    PRINT
    PRINT 'ENTER TANKS PRESENT LOAD DATA'
    GO TO 553


565 LET D5=D1
    LET D6=D2
    FOR N1=1 TO 46
    LET D7=(Y(N1,2)-Y(N1,1))/100
    LET D5=D5+(D7*Y(N1,10))
    LET D6=D6+(D7*Y(N1,11))
    NEXT N1
    LET K3=D5/12
    LET K4=INT(K3)
    LET K3=(((K3-K4)*12)+.05)*10
    LET K3=INT(K3)/10
    PRINT 'DRAFT BASED ON PRESENT LOAD IS'
    PRINT '   ','FEET','INCHES'
    PRINT 'FORWARD',K4,K3
    LET K5=D6/12
    LET K6=INT(K5)
    LET K5=(((K5-K6)*12)+.05)*10
    LET K5=INT(K5)/10
    PRINT 'AFT',K6,K5
    PRINT
    RETURN
```

```
    REM  **********************
    REM  SUBROUTINE 600
    REM  ROUTINE TO CONVERT GALLONS TO TONS AND BARRELS
    REM  STORE IN ARRAY Y AND ECHO TO USER
    REM  T   - LOAD IN LONG TONS
    REM  B1  - PRESENT LOAD IN BARRELS
    REM  **********************


600 PRINT
    LET T=(G*Y(C1,9))/2240
    LET Y(C1,C2)=T
    IF C2=1 THEN 610
    LET B1=G/42
    LET Y(C1,6)=B1
    LET Y(C1,3)=G
    LET Y(C1,4)=F
    LET Y(C1,5)=I
610 PRINT
    PRINT 'SPACE I.D.','FEET','INCHES','GALLONS'
    PRINT L1,F,I,G
    PRINT
    RETURN



    REM  **********************
    REM  SUBROUTINE 650
    REM  CONVERTS TANK SOUNDINGS TO GALLONS'
    REM  V3   - POINTER TO ARRAY X OF LOCATION OF
    REM         INTERPOLATING COEFFICIENTS DESIRED
    REM  G    - TANK CONTENTS IN GALLONS
    REM  **********************


650 LET V3=Y(C1,16)
651 IF S7 LE X(V3) THEN 670
    LET V3=V3+4
    GO TO 651
670 LET G=((S7**2)*X(V3+1))+(S7*X(V3+2))+X(V3+3)
    GOSUB 600
    RETURN
```

```
    REM  **********************
    REM  SUBROUTINE 800
    REM  COMPUTES STRESS FOR THE THREE STRESS CONDITIONS
    REM  T   - NOW REFERS TO THE SHIP DISPLACEMENT
    REM  S2  - SAGGING STRESS
    REM  H   - HOGGING STRESS
    REM  S1  - STILLWATER STRESS
    REM  **********************

800 LET T=13460
    LET S2=6.17
    LET H=5.13
    LET S1=0.99
    FOR N1 =1 TO 46
    LET H1=(Y(N1,2)-Y(N1,12))/100
    LET H = H+(H1*Y(N1,13))
    LET S2=S2+(H1*Y(N1,14))
    LET S1=S1+(H1*Y(N1,15))
    LET T = T+Y(N1,2)
    NEXT N1

    GOSUB 850
    LET S2=S2+S8
    LET S1=S1+S9
    LET H=H+H9
    PRINT
    PRINT 'STRESS IN TONS /SQ.IN., DISPLACEMENT IN LONG TONS'
    PRINT 'HOG','SAG','STILLWATER','DISPLACEMENT'
    PRINT H,S2,S1,T
    PRINT
    LET F1=1
810 PRINT 'DO YOU WANT A HARD COPY OF PRESENT STATUS'
    GOSUB 250
    IF A=1 THEN 812
    IF A=2 THEN 820
    PRINT 'INPUT VALUE INCORRECT'
    GO TO 810
812 PRINT 'ENTER YOUR NAME'
    READ N$
    PRINT 'ENTER DATE. MO,DY,YR'
```

```
      READ M1,M2,M3
      PRINT 'ENTER TIME, IN HUNDREDS OF HOURS'
      READ T5
      PRINT
      PRINT 'ENTER NO. OF PRINTER COPIES DESIRED'
      READ A
      FOR N1=1 TO A
      PRINT 'PREPARED BY-    ',N$
      PRINT 'DATE-    ','MONTH','DAY','YEAR'
      PRINT '     ',M1,M2,M3
      PRINT 'TIME-       ',T5
      PRINT
      PRINT
      PRINT
      PRINT 'SPACE','FEET','INCHES','GAL','TONS'
       FOR N2=1 TO 41
        PRINT Y(N2,7),Y(N2,4),Y(N2,5),Y(N2,3),Y(N2,2)
       NEXT N2


       FOR N2=42 TO 46
        PRINT Y(N2,7),' ',' ',' ',Y(N2,2)
       NEXT N2

      PRINT
      PRINT
      PRINT 'DRAFT','FEET','INCHES'
      PRINT 'FORWARD',K4,K3
      PRINT 'AFTER   ',K6,K5
      PRINT
      PRINT
      PRINT 'STRESS'
      PRINT 'HOG','SAG','STILLWATER','DISPLACEMENT'
      PRINT H,S2,S1,T
      PRINT
      PRINT
      PRINT
      NEXT N1


  REM  **********************
  REM  ROUTINE TO OUTPUT  TO TAPE
  REM  DEPENDING ON SYSTEM IN USE, IF POSSIBLE SAVE
  REM  COLUMNS 1-6 OF ARRAY Y FOR NEXT USE OF PROGRAM.
  REM  **********************

820 RETURN
```

```
  REM  ********************
  REM  SUBROUTINE 850
  REM  COMPUTE STRESS CORRECTIONS FOR DISPLACEMENT
  REM  USING NESTED MULTIPLICATION
  REM  ********************

850 LET T5=T/10000
    LET S9=W(1,7)
    FOR N1=1 TO 6
    LET J1=7-N1
    LET S9=S9*(T5-U(1,J1))
    LET S9=S9+W(1,J1)
    NEXT N1

    LET S8=W(2,6)
    FOR N1 =1 TO 5
    LET J1=6-N1
    LET S8=S8*(T5-U(2,J1))
    LET S8=S8+W(2,J1)
    NEXT N1

    LET H9=W(3,6)
    FOR N1=1 TO 5
    LET J1=6-N1
    LET H9=H9*(T5-U(3,J1))
    LET H9=H9+W(3,J1)
    NEXT N1

    RETURN
```

APPENDIX B

SAMPLE PROGRAM RUN

```
DO YOU WANT THE INSTRUCTIONS
IF YES, INPUT 1.  IF NO, INPUT 2.
2

DO YOU WANT TO CHANGE DAY 1 DATA
IF YES, INPUT 1.  IF NO, INPUT 2.
1

INPUT DAY 1 FORWARD DRAFT.  FEET, INCHES
25, 0

INPUT DAY 1 AFT DRAFT.  FEET, INCHES
25, 10

ENTER DAY 1 LOAD DATA AS FOLLOWS

ENTER NO. OF TANK OR SPACE TO BE CHANGED
IF YOU DO NOT WANT TO CHANGE ANY MORE
DATA, ENTER A NEGATIVE NO.
310

INPUT TANK SOUNDING.  FEET, INCHES
17, 9

SPACE I.D.        FEET          INCHES          GALLONS
    310            17             9            56328.2

ENTER NO. OF TANK OR SPACE TO BE CHANGED
IF YOU DO NOT WANT TO CHANGE ANY MORE
DATA, ENTER A NEGATIVE NO.

3900

ENTER CONTENTS IN LONG TONS
1525
VALUES ENTERED-  SPACE I.D.      TONS
                   3900          1525

ENTER NO. OF TANK OR SPACE TO BE CHANGED
IF YOU DO NOT WANT TO CHANGE ANY MORE
DATA, ENTER A NEGATIVE NO.
-1
```

```
DO YOU WANT TO CHANGE PRESENT LOAD DATA
IF YES, INPUT 1.  IF NO, INPUT 2.
2

DRAFT BASED ON PRESENT LOAD IS
                    FEET            INCHES
FORWARD              25               0
AFT                  25              10

STRESS IN TONS/SQ. IN., DISPLACEMENT IN LONG TONS
   HOG          SAG          STILL WATER          DISPLACEMENT
  6.127        4.321            2.418                28420

DO YOU WANT A HARD COPY OF PRESENT STATUS
IF YES, INPUT 1.  IF NO, INPUT 2.
2

TO CONTINUE, INPUT 1.  TO TERMINATE, INPUT 2
2
DO YOU REALLY WANT TO STOP?
IF YES, INPUT 1.  IF NO, INPUT 2
1
```

APPENDIX C

SAMPLE OF INITIALIZING DATA

ARRAY X

```
X(1) =  1.25
X(2) = 19.4181     TANK 6-A-O-W FIRST SUBCURVE
X(3) =  8.5273     FROM 0 TO 1.25 FEET
X(4) =  1.

X(5) =  4.9167
X(6) = 25.3057     TANK 6-A-O-W SECOND SUBCURVE
X(7) = 99.1423     FROM 1.25 TO 4.9167 FEET
X(8) =125.1719
  .       .
  .       .
  .       .
```

ARRAY Y

DATA FOR 6-A-O-W

```
Y(1,7)  =  00        I.D. NUMBER
Y(1,8)  =  45.1      MAXIMUM SOUNDING
Y(1,9)  =   8.5      SPECIFIC GRAVITY
Y(1,10) =   5.69     CHANGE IN DRAFT FORWARD, INCHES/100 TON
Y(1,11) =  -2.326    CHANGE IN DRAFT AFT, INCHES/100 TONS
Y(1,12) =   0        COLUMN A, FIGURE 3
Y(1,13) =    .114    COLUMN D, FIGURE 3 (HOGGING)
Y(1,14) =  - .11     COLUMN D, FIGURE 3 (SAGGING)
Y(1,15) =    .114    COLUMN D, FIGURE 3 (STILLWATER)
Y(1,16) =   1        STARTING POINT IN ARRAY X
  .       .
  .       .
  .       .
```

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